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ASSISTANT SECRETARY OF THE ARMY
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WASHINGTON, D.C. 20310-0103

ARMY SCIENCE BOARD

FINAL REPORT

of the

ARMY SCIENCE BOARD (ASB) PANEL

on

ELECTROMAGNETIC/ELECTROTHERMAL GUN TECHNOLOGY DEVELOPMENT

10 December 1990

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ABSTRACT

By language included in the 1990 Defense Authorization Conference Report Number 101-331, the Army Science Board (ASB) was directed to monitor progress of the electromagnetic/electrothermal gun technology development program and to report to the Secretary of the Army; the Secretary was asked to provide summary reports of ASB findings to the Congress with the budget submissions for fiscal years 1991 and 1992. An ASB Panel was duly established; the initial Panel report was dated 18 December 1989. This second and final report fulfills all ASB responsibilities indicated in the Congressional directives and the Panel Terms of Reference.

As a result of the Panel's evaluations during the past year, questions are raised and conclusions are drawn relative to current program efforts. It is concluded that electric gun technology represents an area of long-term importance to U.S. armed forces, with the potential to furnish a variety of applications; it is emphasized, however, that potential benefits can be realized only through a consistently-funded program providing additional emphasis on the illumination of fundamental issues, the maturation of component technologies, and the identification of innovative system applications.

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As a result of the Panel's evaluations during the past year, questions are raised and conclusions are drawn relative to current program efforts. It is concluded that electric gun technology represents an area of long-term importance to U.S. armed forces, with the potential to furnish a variety of applications; it is emphasized, however, that potential benefits can be realized only through a consistently-funded program providing additional emphasis on the illumination of fundamental issues, the maturation of component technologies, and the identification of innovative system applications.

SECTION I.

INTRODUCTION

INTRODUCTION

The Senate Armed Services Committee Report Number 101-89 of 19 July 1989 included the following words: "The committee expects the Army Science Board to monitor the electromagnetic/electrothermal gun development program during the next two years, and to report to the Secretary of the Army on progress in this technology. The Secretary shall relay a summary report of their findings to the Congress with the budget submissions for fiscal years 1991 and 1992." Similar language was provided in the 1990 Defense Authorization Conference Report Number 101-331. In response, the Acting Assistant Secretary of the Army for Research, Development and Acquisition, Mr. George E. Dausman, by letter of 23 October 1989 (Appendix A) to the Chair of the Army Science Board , Mr. Gilbert F. Decker, requested appointment of a suitable panel; identified Terms of Reference; and requested an initial panel report prior to 20 December 1989.

As stated, the Terms of Reference require that the panel:

"a. Examine the overall program structure, monitor and evaluate the progress of the technical efforts against goals and timelines.

b. Monitor the status of component technologies (power supplies, accelerators, advanced projectiles, cartridges and in the case of ET, propellant) and provide updates to the conclusions of previous independent analysis and reports.

c. On the basis of your evaluation of the progress within the program, recommend program changes or restructuring if required to effectively meet stated program goals."

The initial report of the Army Science Board (ASB) Panel was furnished to the Chair, Army Science Board, on 18 December, 1989 (Reference 1); transmitted to the Secretary of the Army on 6 February, 1990, by letter from the Acting Assistant Secretary of the Army. The current Panel report fulfills all responsibilities indicated in the Congressional directive and the Panel Terms of Reference.

Panel activities during CY1990 are outlined in Section II; critical issues are identified and discussed in Section III; Panel conclusions are presented in Section IV.

Appropriate acknowledgments, references and the required Conflict of Interest Statement are included in Sections V, VI and VII, respectively. Supporting material is furnished in Appendices A through J (cf. Table of Contents, p. i); particular mention should be made of Appendices E and F, providing information regarding the Army's current electric armament program, as furnished by Mr. Gregory E. Ferdinand, Chief, Electric Armaments Program Office.

SECTION II.

PANEL ACTIVITIES IN 1989 AND 1990

PANEL ACTIVITIES

NOVEMBER 1989

The initial meeting of the Panel was held on 27, 28 and 29 November 1989, at the US Army Armament Research, Development and Engineering Center (ARDEC) located at Picatinny Arsenal, New Jersey. It was conducted in order to provide the ASB Panel with an overview and detailed technical presentations relating to all aspects of the Electromagnetic/Electrothermal Gun program.

DECEMBER 1989

The second meeting was held in Arlington, Virginia on 12 and 13 December 1989 to draft an initial report as required by the Terms of Reference from the 23 October 1989 Assistant Secretary of the Army (Research, Development and Acquisition) letter.

A third meeting was held 18 December 1989 to finish the draft report and to brief Mr. George T. Singley III, Deputy Assistant Secretary for Research and Technology.

JANUARY 1990

Dr. Gary A. Thiele, Vice Chair of the Panel, attended a series of briefings at Green Farm, a test facility near San Diego, and witnessed a shot from an Electrothermal-Chemical Gun.

MARCH 1990

Dr. Gary A. Thiele, Vice Chair of the Panel, attended the Office of the Secretary of Defense (OSD) electric gun Topical Review Workshop on 5 through 9 March 1990 held in Arlington, Virginia. He presented the results of the ASB Initial Report.

APRIL 1990

The Panel met on 26 April 1990 in Arlington, Virginia to (a) review events/changes in the program since the 18 December 1989 report writing session, (b) determine the necessary steps required to formulate the Study Plan for the remainder of the Panel term, and (c) be briefed on the OSD Workshop.

JUNE 1990

The Panel met in San Diego on 7 June 1990 to attend a briefing at Maxwell Laboratories, Incorporated on capacitor technology. A briefing was also presented by Sparta, Incorporated on barrel technology. In addition, the Panel witnessed an EM rail gun shot at Green Farm.

JULY 1990

A meeting of the Panel was convened on 19 July 1990 at the Center for Electromechanics (CEM) and the Institute for Advanced Technology (IAT), a Federally Funded Research and Development Center (FFRDC), of the University of Texas. The Panel was briefed on CEM capabilities and the Compulsator Driven Railgun system.

SEPTEMBER 1990

The Panel met on 25 September 1990 at the US Army Armor Center, Fort Knox, Kentucky. The Panel received a threat briefing and an armor/anti-armor briefing.

OCTOBER 1990

The Panel met on 1 October 1990 at the Ballistic Research Laboratory, Aberdeen, Maryland. The Panel was briefed on the GT-Devices ETC propulsion program.

The Panel met 24 through 26 October 1990 at the US Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey, to draft its final report as required by the Terms of Reference.

SECTION III.

FINDINGS/COMMENTS

SUMMARY COMMENTS ON ELECTRIC GUNS

We believe the Army should continue a vigorous EM/ET Gun Technology Development Program. EM Gun Systems, in particular, promise important advantages over conventional gun systems due to the elimination of black powder; i.e., greater crew safety, elimination of gun flash (blast signature), and decreased logistics costs. In addition, EM guns, and to a lesser extent ETC guns, have the potential to provide hypervelocity and/or hyperenergy projectiles -- although it must be recognized that further efforts are necessary to understand and quantify the possibilities and difficulties associated with hypervelocity/hyperenergy projectiles.

ETC technology provides an important advantage over EM technology in that the typical ETC gun system requires fully one order-of-magnitude less electrical power, thereby offering nearer-term promise for Army mobile applications. On the other hand, the ETC program has not lived up to expectations within the current "window of opportunity" because of the current lack of understanding of the physics and chemistry of the processes that occur within the breech and gun barrel. This lack of understanding of ETC propulsion has made it impossible to predict the performance of an ETC gun to an acceptable degree. It is certainly possible, however, that the ETC gun may evolve into a workable system at a later time if research into ETC internal combustion processes is pursued now. In fact, to close the door on this aspect of ETC gun technology would open up the possibility of technological surprise by potential adversaries should they be the first to gain a fundamental understanding of the physics and chemistry of ETC propulsion.

By way of comparison, EM gun technology is not hampered by a lack of understanding of the physics involved; indeed, the physics is well understood. The current problems with EM gun technology relate to engineering difficulties associated with the rail gun, the accelerator of choice by most workers in the field. There are, however, other configurations that may avoid many of the serious problems now plaguing development of the rail gun accelerator; for example, coil guns and multi-rail guns represent alternate configurations deserving further investigation. Furthermore, some of the problems may be made more tractable by considering the synergistic benefits of designing the accelerator and power supply together as a system.

It is also important to note that EM gun technology development may lead to a wide variety of applications. For example, in addition to the obvious tank role, versions of the gun might be used as an air defense weapon, an anti-tactical ballistic missile weapon, or a satellite launching device.

THE GLOBAL SCENE

The twelve-month period from November 1989 to November 1990 has witnessed some of the most profound and far-reaching geopolitical changes of this century. The USSR no longer exercises hegemony over Eastern Europe. The two Germanys are now one. There is a serious economic crisis in many of the East Bloc countries and the beginning of withdrawal of Soviet troops from former Warsaw Pact countries. There is a greater freedom of movement among countries and increasing support, both in the US and Europe, for a smaller US presence and role.

On the other hand, the Mideast, long an area of localized conflicts, has, since August 1990, turned into an international battlefield. The United Nations forces face an enemy equipped with a polyglot of modern weapons purchased from both Western and Eastern countries and frequently modified indigenously to fit their own tactical needs. The terrain is far less familiar than the Fulda Gap, and both climate and terrain make combat operations and sustainment of combat troops and equipment far more difficult than for operations in Western Europe.

At the same time we see the changes in Europe and the Mideast ,we face a critical US national budget deficit. There is enormous pressure to decrease federal spending, particularly defense spending. If one assumes a settlement of the Iraqi crisis by any means short of combat, then one can prudently speculate that the sentiment to reduce defense spending will persist for some time into the future.

The pace of change has been so rapid that the Army has not completely rethought its strategy, tactics, plans, and budget requirements. Part of this delay results from prudent caution: Can we really trust the Soviets? Part relates to the fact that the world today is so different. Army planners need to go back to the very basics to arrive at a sound philosophy for the Army of the 21st Century.

Within this huge array of changes there are several plausible hypotheses that will impact the Army electric gun program. These include:

1. Economic and military factors will cause the Soviets to delay design, production, and fielding of the Future Soviet Tank.

2. Economic and military factors will cause the US to delay production and fielding of the Block III and Block IV Tanks.

3. The US will, in the future, have a higher probability of facing Third World threats from countries such as Iraq. These countries will possess a heterogeneous mix of modern weapons. The terrain will be unfamiliar and inhospitable, and enemy tactics may be alien to Western military thinking. In particular, the US may need to fight an offensive war from ill-prepared positions rather than, as in Western Europe, a defensive war from exquisitely prepared positions.

4. The US will of necessity face up to the deployment problems so apparent during Desert Shield.

These factors bear on the need for future tanks and future tank gun systems as well as the tactical use of armor and anti-armor weaponry.

SOME CONSIDERATIONS RELATING TO HYPERVELOCITY

The Army electric gun program is often discussed in terms of higher velocity projectiles. It is useful to review the utility of higher velocities in the context of important uses: anti-tank; artillery; and air defense. Our conclusion is that for most of those missions for the near future, higher velocity is not critical.

Tanks are attacked from the front (where the armor is thickest), or the top, sides, or even the bottom. Existing gun systems, with ordinary improvements, seem adequate for all threat tanks except frontal attack against hypothetical tanks not yet fielded. Increased muzzle velocity might allow penetrators successfully to attack the front of any potential threat, but this is doubtful since bolt-on armor packages represent a straightforward way to offset modest increases in muzzle velocity. An ancillary benefit of higher velocity would be higher accuracy, since a tank at a fixed distance would have less time to move.

Two key aspects of conventional artillery are: (1) "zoning" which means that a combination of charge plus elevation angle of fire places the round in a particular (distance) zone (i.e., variable muzzle velocities are employed); and (2) "high precision" which means rounds must achieve muzzle velocities within 0.2% of the expected velocity over the range of velocities used by a particular artillery gun. Thus any new artillery gun system must be able reliably to reproduce its performance over a range of muzzle velocities (not just at a single muzzle velocity).

Another artillery consideration is the huge stockpile of 155mm ammunition. It would be highly desirable to provide enhancements to present gun propulsion systems that allow the use of this stockpile. Such a requirement would put an upper limit on the useful velocity for a 155mm system since there is a limit to the forces the shells can take. We are not sure that a 40% increase in energy (20% in velocity) is consistent with this constraint.

In air defense, higher velocities decrease the time from initial target detection to intercept. However, even extraordinary velocities, e.g., 5 km/sec, still allow significant maneuvering time for a target at a range of 5 to 10 km. Thus, at these ranges, smart projectiles seem imperative, and very high velocities do not seem critical. High velocity does seem useful for close-in air defense, but this is not the chief emphasis of the programs presented to the Panel.

In summary, the principal performance advantage of higher velocities (at least for energies above 5 MJ per shell) is for front-attack KE tank rounds. While there are strong arguments for dumb munitions that work from close ranges outward, the opportunities for bolt-on defensive armor packages make it hard to guarantee success. (At least for some kinds of penetrators, penetration is proportional to $V^{2/3}$, and V is proportional to $E^{1/2}$, so a 30% increase in energy is defeated by 10% more armor capability.)

STATE OF ETC TECHNOLOGY

Events of the past year make Electrothermal-Chemical (ETC) technology seem much less mature and therefore less promising for the near future than it seemed a year ago. In our 1989 report, we stated (p. 12), "The most interesting of the Army programs are those we describe as feasibility checks. Based on test firings underway now, the Army will decide during the first quarter of calendar year 1990 whether ETC technology can operate adequately with 120mm barrels. If not (the off ramp), the present tank ETC program would be terminated." This was the Army Science Board's assessment of the Army program, and not necessarily the Army's up-to-date plan.

The test firings did not live up to expectations at all, not in muzzle energy, not in reproducibility, not in control of pressure, and in all ways showed that there is no adquate understanding of combustion in ETC guns. As contrasted to electromagnetic gun technology, the understanding of the basic physics underlying the ETC technology is not in hand.

Without predictable muzzle energy, good reproducibility, and controlled pressures, among other things, ETC is not a plausible technology for use in tank guns or artillery. Adequate models of what happens in the chamber are a prerequisite to progress. The physics and chemistry of ETC combustion need to be better understood, at least to the point where some empirical models can provide good predictions.

It is worth looking at some of the other potential advantages of ETC. The working fluid may be less vulnerable than gunpowder, but since no one knows what the working fluid will be, comparison with projected conventional propellants is not yet possible. The same holds for potential logistics benefits.

One of the components of the ETC gun program has been the development of high energy density batteries and high power density capacitors. These power devices have wide applicability throughout the Army (for instance in the Directed Energy Weapons program), and the advancements in this technology as a result of the Electric Gun program have been remarkable.

THE ELECTROMAGNETIC GUN SYSTEM

As compared to the electrothermal gun, the basic physics issues associated with the electromagnetic gun paradoxically are less complicated and more fully understood, while the engineering problems are very difficult. The electromagnetic gun definitely offers the possibility of increased velocity although, as noted earlier in this section, the utility of such increased velocity is not clearly established. However, there are several other advantages that an electromagnetic gun brings to a tank. The gun tube could be smaller and lighter for comparable ranges and velocities. There would be no black powder or similar combustible propellants stored on the tank, and the number of stowed rounds could be increased. The supporting consumables could be reduced to fuel and projectiles. There would be a great synergism with the Army's proposed all-electric family of vehicles. Proper design would result in lower visual and blast signatures. There would be a lessening in safety hazards such as unscheduled ignitions, misfires, and flarebacks.

On the other hand, the electromagnetic gun system might well bring an entirely new set of problems. We have never packaged several megajoules of energy within the confines of a tank. The prospect of a lithium sulfide battery operating at 400°C within a few feet of a soldier is indeed sobering.

We noted in our last report and reiterate here that the Army needs a new and/or improved gun system, not simply an electromagnetic gun. The system must include a means to move the gun to a fighting position, acquire a target, lay the gun on the target, fire a projectile, hit the target, and kill a target not once, but repetitively. These system problems, for the electromagnetic gun, are truly formidable. We expect no solution in this century.

The Army has concentrated its electromagnetic gun program (EM Rail) for one application: anti-armor. Funding limits and the need for program support from the user community led to these decisions.

The railgun technology has a number of problems, most of which have to do with turning an understood laboratory principle into a system. There are other methods of providing electromagnetic acceleration; some are discussed in Appendices G and H.

We can foresee a number of possible uses for the rail gun beyond a tank gun. The Hardison Report (Reference 10) more fully examines these options. A small caliber EM gun would not require the extraordinary power that is needed for the tank gun. A close-in air defense gun or an anti-ballistic missile weapon system would seem to be possibilities to be examined.

ENERGY CONVERSION SYSTEMS

Development of the railgun and associated energy conversion equipment is not hampered by inadequate knowledge of physics, but by very difficult engineering problems that seem to be appearing much faster than they can be solved. For example, there is a force between the rails carrying more than one million amperes that tends to turn the barrel into an ellipse. This causes air gaps to appear between the rails and the projectile base in which arcs are established. These arcs burn the rails, making it necessary to recondition them after every test run. All developers have taken the brute force approach to solving the problem; they stiffen the barrel. This has necessitated the development of new dielectric materials and methods of fabrication, with a very large additional expenditure of time and money.

Adaptation of the railgun as the only possible projectile accelerator has forced the developers to restrict their attention to two distinct types of energy conversion equipment: the battery/capacitor and the compulsator.

The compulsator is commutated, rotating equipment that combines inductance and capacitance such that pulses of power can be provided to the railgun with optimally designed waveform. The electrical phenomena associated with this complex device are well understood, but the design requires very challenging application of advanced materials and fabrication techniques. The Center for Electromechanics at the University of Texas at Austin has done a remarkable job in developing this device. So far it promises a higher specific energy than the capacitor-centered technology being developed by Maxwell Laboratories, Incorporated and elsewhere.

Thin film, all solid-state thermovoltaic batteries inherently have very large capacitance; hence, it is possible to combine the battery and the capacitor in the same space, thereby, maximizing the specific energy and the specific power of battery/capacitor energy conversion equipment. Ideas like this have been the subject of the DARPA EG program. With DARPA's exit from this technology, a new base of support must be found.

In both the battery/capacitor and compulsator, development is hampered by the inflexible demands of the railgun; i.e., one million amperes or more. Other methods of EM propulsion, including the coilgun, could conceivably operate with higher voltages and lower current, making the energy conversion problem less formidable. In addition, other methods of propulsion could use the power more efficiently than a railgun, thereby requiring a substantially smaller and lighter power system. Currently, railguns are utilizing power at approximately 25% efficiency. The search should be how to operate at 50% efficiency or more.

Thought needs to be given to designing the accelerator and power supply together. To date accelerator designers have relied upon known characteristics of existing power conversion equipment to provide their particular electrical needs. Little advantage has been taken of the benefits that would accrue if the accelerator and power conditioning equipment were designed together to achieve more compactness and greater efficiency. For example, a multi-rail gun would require greater current but lower voltage, which would be more compatible with a high power density battery. Also, it would have a higher efficiency by reducing the arcs associated with non-axi-symmetric stresses on the barrel of conventional rail guns. Similarly, coil guns with properly matched power supplies would operate at higher efficiency due to the elimination of contact losses.

The resulting savings in size and weight of matched accelerator/power conversion equipment may make it feasible to install the entire system, including the projectile loader, on the movable gun mount. For example, a recent DARPA SBIR REP calls for R and D on batteries capable of deliverying 10^5 to 10^6 watts/kg. If this goal is achieved, and if such a battery were matched with a multi-rail gun, which also must be developed, a very compact gun system could be built.

FUNDING

The Army funding for the Electric Gun Program (in Millions of dollars) is:

FY90	FY91	FY92	FY93	FY94	FY95
$42.4	$35.1	$49.3	$47.3	$76.9	$45.2

The Army, of course, is only one of many players in the electric gun arena. The total DoD funds committed to electric gun or electric gun-related technologies will be in the neighborhood of $150 Million during the next two Fiscal Years. We noted in last year's report (Paragraph E of the Comments Section, page 15) that leverage is a two-edged sword. The Army with its $40 (plus or minus) Million investment can profit from a total of $150 Million of electric gun research. However, the Army has little control over funding from extra-Army sources. Changes in emphasis, changes in budget levels, changes in leadership at other agencies, and other changes can result in funding decrements that can quickly decimate the program or critical elements of the program. This reality was vividly illustrated this year as DARPA withdrew all Electric Gun funds effective with FY92.

OTHER COMMENTS

A. We were impressed with the facilities and personnel at the Center for Electromechanics at the University of Texas at Austin. The engineers and scientists who are a part of the Army's electromagnetic gun program are competent, enthusiastic, and completely aware of the basic requirements for conducting a research program.

B. The geographic proximity of the Institute for Advanced Technology, the Army's FFRDC at the University of Texas at Austin, should ensure a close tie with CEM that augurs promising results for the Army. The initial staffing at the FFRDC is impressive. However, the funding of the Institute is so minimal that little by way of substantive results can be expected in the immediate future.

C. We have noted earlier our reservations concerning the needs for higher velocity, particularly as the Future Soviet Tank may not materialize. The Army has selected the 140mm tank gun as a candidate to "get within the turning radius" of this Soviet Tank Concept. We would be remiss if we did not indicate the large amount of "user" dissatisfaction we found with this decision. The unhappiness centered around the small number of stowed rounds possible with the 140mm ammunition and the difficulty in handling the large two-piece ammunition.

SECTION IV.

CONCLUSIONS

February 13, 1991

CONCLUSIONS

1. Electric gun technology represents an area of long-term importance to the U.S. armed forces; however, potential benefits can be realized only through a consistently-funded, coherently-managed program providing additional emphasis on the illumination of fundamental issues, the maturation of component technologies, and the identification of innovative system applications.

2. None of the present electric gun concepts will result in a complete, ready-to-field system in the near future; therefore, it would seem that performance demonstrations should be limited at this time to those essential to in-depth understanding of physical phenomena or program status (e.g., to tests comparing theory and practice for propulsion techniques, materials development or projectile design).

3. At this time, electrothermal-chemical (ETC) technology does not appear to be a promising avenue for solving the Army's needs for advanced ammunition propulsion systems. The technology, in its present status, still requires a high-risk and lengthy research program to deliver even modest improvements over present propulsion methods. **(We emphasize that this conclusion is a change from last year's report and is based on our study and analysis during this past year.)**

4. The current lack of promise for ETC technology should result in an orderly shifting (by the Army) of program and funding emphasis to other electric gun technologies; in particular, electromagnetic (EM) gun technology should be given additional support. In this connection, the Army should consider approaches other than (in addition to) the rail gun as a means of electromagnetic propulsion. Remaining ETC gun efforts should be directed toward understanding the basic phenomenology of ETC propulsion.

5. Power generation is still the critical technology for large electric guns. The Army's program to develop power sources and power conditioning devices, such as batteries, condensers and compulsators, has wide utility and deserves vigorous support.

6. In the process of considering alternatives to current rail gun concepts, a "systems approach" should be employed in an attempt to minimize engineering problems; for example, there should be efforts to alleviate problems of cabling, switching, etc. by planning to match the power generation/storage subsystems to the method of propulsion.

7. Further efforts are needed to develop an adequate understanding of the performance/penetration advantages and design difficulties/limitations of hypervelocity and/or hyper-energy projectiles. In this connection, consideration should be given (e.g., for tank armor) to the extent of responsive engineering improvements in armor materials that would be necessary to obviate the apparent penetration advantages of hypervelocity/hyperenergy projectiles.

8. It should be noted that the EM gun program has the potential to furnish a variety of applications. For example, in addition to the obvious tank role, versions of the gun might be used as an air defense weapon, an anti-tactical ballistic missile weapon, or a satellite launching device.

9. The funding for the electric gun program, particularly if funds are shifted from the ETC gun efforts to EM gun efforts, would appear to be sufficient to support rail gun technology development. The planned funding may not be adequate, however, to investigate desirable electromagnetic propulsion alternatives to the rail gun. We feel that discovery of viable alternatives is critical to program success; therefore, additional funding for the over-all program may be warranted.

SECTION V.

ACKNOWLEDGMENTS

ACKNOWLEDGMENTS

The Panel would like to express its appreciation to all speakers associated with the numerous meetings. The information conveyed through briefings and discussions provided the foundation for this review.

The Panel acknowledges the continuing support provided by the ARDEC staff assistants, Mr. Gregory Ferdinand and Mrs. Hildi Naber-Libby. In addition, the Panel would like especially to note the administrative and clerical support provided by Mrs. Nancy Javorsky, Electric Armaments Program Office, ARDEC. Her efforts in respect to the preparation and editing of this report were essential to the effective completion of the Panel's task.

SECTION VI.

REFERENCES

REFERENCES

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6. Summary Report of the Army Science Board (ASB) Ad Hoc Sub-Group for Electromagnetic/Electrothermal Gun Development, Initial Program Review, 27 through 29 November 1989 held at U.S. Army Armament Research, Development and Engineering Center.

7. SECRET; Appendix to the Summary Report of the Army Science Board (ASB) Ad Hoc Sub-Group for Electromagnetic/Electrothermal Gun Development, Initial Program Review, 27 through 29 November 1989 held at U.S. Army Armament Research, Development and Engineering Center.

8. White Paper on Hypervelocity, Dr. W. Derosett, Ballistic Research Laboratory.

9. Congressional Language, (Appendix C).

10. SECRET; Defense Advanced Research Projects Agency (DARPA) Electrical Energy Gun System Study, Final Report Briefing, 5 April 1989 (Hardison Report).

11. Tutorial on Electric Gun Systems from background material packet transmitted by U.S. Army ARDEC letter, SMCAR-FSC, 3 November 1989.

12. Army/DARPA/DNA/USA Electric Gun System Investment Strategy Panel viewgraphs, 1989.

13. SECRET/NOFORN/WINTELL; U.S. Army Armor/Anti-Armor Master Plan, FY89, Phase I, Volume I, Headquarters, Department of the Army, DAMO-FDD, 17 May 1988.

14. SECRET/NOFORN/WINTELL; U.S. Army Armor/Anti-Armor Master Plan, FY89, Phase II, Volume II, Headquarters, Department of the Amry, DAMO-FDD, 1 October 1988.

15. SECRET; Briefing, Armored Systems Modernization and Block III Main Battle Tank, Director, Combat Developments, U.S. Army Armor School, Fort Knox, Kentucky, as presented to Army Science Board EM/ET Panel, 25 September 1990.

16. CONFIDENTIAL; Final Report, DOD Electric Gun Topical Review, DDR&E/R&AT-ET, Washington, DC 20310-0103, May 1990.

17. One-page Summary, Coil Gun Research at Sandia National Laboratories, Mr. Thomas Hitchcock, 25 October 1990 (Appendix H).

18. Extract, DP Selection Criteria, Enclosure to Memorandum of Understanding between the Ballistic Research Laboratory, Aberdeen, MD and the US Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, Final Draft version, October 1990 (Appendix F).

19. Sponsorship Agreement, Federally Funded Research and Development Center (FFRDC) at the Institute for Advanced Technology (IAT), The University of Texas at Austin, Austin, TX, 1 November 1990.

20. DOD Joint Electric Armaments Committee (JEAC) Draft Charter, 24 October 1990.

21. US Army Technology Base Master Plan, published in November 1990.

22. DOD Critical Technology Listing, facsimile copy dated 29 June 1990.

SECTION VII.

CONFLICT OF INTEREST STATEMENT

CONFLICT OF INTEREST STATEMENT

By letter of 26 October 1989, the Executive Secretary of the ASB furnished to the Panel Chairman a copy of a memorandum from the ASB Ethics Counselor, stating that a review of the Terms of Reference and the membership list had identified no apparent conflicts of interest (Appendix G). It was requested, however, that continuing attention be given to the matter of potential conflicts, and that Panel reports should include (or be accompanied by) a statement by the panel chair "either describing conflicts that have become apparent as a result of the panel's recommendations, or confirmation that there were no conflicts identified".

It is hereby confirmed by the panel chairman that no conflicts of interest have been identified.

Alvin R. Eaton

Alvin R. Eaton

APPENDIX A

Tasking Letter

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

23 OCT 1989

SARD-ASB

Mr. Gilbert Decker
Chairman, Army Science Board
Penn Central Federal Systems Company
1800 Diagonal Road
Suite 500
Alexandria, Virginia 22314-2840

Dear Mr. Decker:

The Army has accelerated its plans to evaluate electromagnetic (EM) and electrothermal (ET) guns. An independent analysis conducted for the DoD indicates substantial promise in this technology. That analysis found that EM/ET gun applications can be anticipated earlier with proper focus and demonstration. The Senate Armed Services Committee in its report, #101-89, dated 19 July 89, expects the Army Science Board to monitor the EM/ET gun development program during the next two years and report to the Secretary of the Army on progress of this technology. The Secretary will relay a summary report of the findings to the Congress with the budget submissions for fiscal years 1991 and 1992.

You are requested to appoint a panel of six to eight Army Science Board members to study the Army's EM/ET gun development program and to prepare a report on progress of that technology prior to 20 December 1989. Following the submission of that report, your Board is to continue to monitor the EM/ET gun development program and submit a second report by 1 December 1990.

The panel should address, as a minimum, the Terms of Reference (TOR) described below.

I. Background

The possibility of developing emerging electric propulsion technology for applications to direct and indirect fire weapons has become more promising over the last five years. From limited, small scale laboratory experiments, the technology has evolved to a point where weapon level performance can be anticipated in the foreseeable future.

The focus of this technology is on three candidate approaches: electromagnetic railguns, electromagnetic coilguns and electrothermal guns. All three candidates employ electrical pulse power to generate the energy needed to propel the projectile to hypervelocities (velocities greater than two kilometers/sec) at the muzzle.

Electromagnetic railguns employ a simple geometry of two parallel, low impedance conductors connected together through a solid armature attached to the projectile or through a plasma armature just behind the projectile. The magnetic field created by the current flow through the first conductor, across the armature and back through the second conductor propels it through the barrel.

Electromagnetic coilguns employ a more complex geometry of driver coils which interact with coils on the projectile to create a magnetic propulsion field.

Electrothermal guns employ a large, shaped electrical pulse fed into the breech. The electrical energy is converted into a plasma (an extremely hot mixture of ions and electrons) in a cartridge of the breech, and this is used to vaporize a "working fluid" in the chamber.

All three of the above candidate concepts share common technology barriers which must be overcome if this technology is to be brought to fruition. In recognition of these barriers and the promise that electric armament technology has to offer, the Army has been directed by the Congress to convene the Army Science Board to monitor this EM/ET gun technology base activity. (The Congressional language is attached.)

II. Terms of Reference

a. Examine the overall program structure, monitor and evaluate the progress of the technical efforts against goals and timelines.

b. Monitor the status of component technologies (power supplies, accelerators, advanced projectiles, cartridges and in the case of ET, propellant) and provide updates to the conclusions of previous independent analysis and reports.

c. On the basis of your evaluation of the progress within the program, recommend program changes or restructuring if required to effectively meet stated program goals.

The study is expected to require numerous briefings as well as visits to some field locations.

MG Beltson will sponsor the study. The Cognizant Deputy will be Mr. George Singley. The HQ DA Staff Assistant will be Ms. Irena Szkrybalo, Acting Director of Technology, ASA(RDA). The Staff Assistant will be Mr. Gregory Ferdinand, Acting Chief, Electric Armaments Program Office, U. S. Army Armaments Research, Development and Engineering Center.

The Panel should begin its work immediately and conclude the initial effort at a two-day summarization and report writing session scheduled for 10 December 1989 at the Pentagon. As a first step, the panel chairman should prepare a study plan and present that plan to the sponsor.

George E. Dausman
Acting Assistant Secretary of the Army
(Research, Development and Acquisition)

APPENDIX B

Membership

MEMBERSHIP

ARMY SCIENCE BOARD PANEL
on
ELECTROMAGNETIC/ELECTROTHERMAL GUN TECHNOLOGY DEVELOPMENT

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APPENDIX C

Relevant Congressional Language

CONGRESSIONAL LANGUAGE EXCERPTS (1989)

1. Senate Appropriation Committee (SAC) , 14 February 1989:

Recommended Increases

"The Committee partially offsets the previously discussed reductions by adding funds to develop higher-payoff armor and antiarmor capabilities as follows: . . . (b) $15,000,000 for accelerated development of electromagnetic and electrothermal antiarmor gun technologies, on a competitive basis . . .

With respect to the electromagnetic/electrothermal gun funding, the Committee is aware of the Army's initiative to establish a new federally funded research and development center for these technologies. The Committee requests a report with the submission of the fiscal year 1991 budget request on the use of appropriate funds to establish this center, including the outcome of the source selection process. The report also should include the extent of coordination of technology developments in this area among all the services and other relevant Federal departments and agencies, including the status of any memoranda of agreement and of any efforts to acquire or construct expanded or additional testing facilities. The Committee expects the Defense Department not to contribute to duplication of federally funded test facilities."

2. House Armed Services Committee (HASC):

Heavy Force Modernization

"In view of the foregoing, the committee recommends approval of all requests for continued work in technology, including an additional authorization of $20 million for competitive development of electro-thermal gun work, and $10 million for competitive demonstration of advanced integrated propulsion systems."

3. Senate Armed Services Committee (SASC), 19 July 1989:

Electrothermal Gun

"The committee notes that the Army has accelerated its plans to evaluate electromagnetic and electrothermal guns. Electrothermal guns hold the promise of substantially higher kinetic energy for greater range and destructive potential. The committee understands that an independent analysis conducted for the Army indicated that electromagnetic and electrothermal gun applications are not so distant a prospect as believed by Army laboratories, nor as available a weapon system as has been promoted by contractors and advocates.

The committee is persuaded, however, that the substantial promise offered by electrothermal gun technology does justify increased funding at this time. Consequently, the committee recommends an added authorization of $25 million for fiscal year 1990 and $35 million for fiscal year 1991. The committee expects the Army Science Board to monitor the electromagnetic/electrothermal gun development program during the next two years and report to the Secretary of the Army on progress in this technology. The Secretary shall relay a summary report of their findings to the Congress with the budget submissions for fiscal years 1991 and 1992."

4. House Appropriation Committee (HAC), 1 August 1989:

Weapons and Muntions Advanced Technology

"The Committee recommends $67,774,000 for weapons and munitions advanced technology, an increase of $19,000,000 to the budget request. Included is an increase of $20,000,000 to accelerate development of electrothermal/electrochemical gun technology, and a decrease of $1,000,000 for the Advanced Field Artillery System under the Heavy Force Modernization concept. The latter is specifically denied."

5. 1990 Defense Authorization Conference Report Number 101-331, to accompany HR Number 2461, 7 November 1989:

Electrothermal Gun

"The House bill recommended an authorization of $20 million above the amended request to support competitive work on electrothermal guns.

The Senate amendment recommended an increased authorization of $25 million for fiscal year 1990 and $35 million for fiscal year 1991, and encouraged the Army Science Board to monitor the program. The Senate report (S. Rept. 101-81) directed the Secretary of the Army to report on assessments of the Army Science Board with the budget submissions for fiscal years 1991 and 1992.

The conferees recommended an increased authorization of $20 million. The funds may not be expended within the Army laboratory system, but must be obligated on a competitive basis in the private sector. Further, the funds must be matched on a dollar-for-dollar basis by each contractor awarded a contract. The Army Science Board is directed to monitor the progress of the funded programs and develop a scheduled plan for testing a selected electro-thermal gun system against the conventional gun system currently being developed preferably during fiscal year 1992, and report to the Secretary of the Army on its findings and recommendations. The Secretary of the Army shall provide a summary assessment of the reports of the Army Science Board to Congress with the budget submissions for fiscal years 1991 and 1992."

6. 1990 Defense Appropriation Conference Report Number 101-345, to accompany H R Number 3072, 13 November 1989:

Weapons and Munitions Advanced Technology

"The conferees agree to provide $77,774,000, which includes a reduction of $1,000,000 for the AFAS advanced technology test bed, an adddition of $10,000,000 for electromagnetic/electrothermal gun technology research on a competitive basis, and an addition of $20,000,000 for a classified project explained in the classified annex to this report. The conferees expect that meeting the requirements for a new artillery system will have one of the highest priorities under the Heavy Force Modernization initiative, once approved by the Secretary of Defense. Continued exploratory development of advanced technologies related to fire support are essential to counter Soviet artillery capabilities. The conferees support the Army's development of a future field artillery system. As part of these efforts, the Secretary of the Army should emphasize advanced artillery gun propulsion technologies such as liquid propellant, uni-charge, and electrothermal. The conferees also agree to the Senate requirement for a report on the establishment of a FFRDC for electromagnetic/electrothermal gun research, to be submitted by the Secretary of Defense."

NATO Research and Development

". . . Furthermore, the conferees agree that no NATO Research and Development funds in either fiscal year 1989 or 1990 may be used for the following projects: . . . Hypervelocity Projectile."

CONGRESSIONAL LANGUAGE EXCERPTS (1990)

1. Senate Armed Services Committee (SASC), 26 July 1990:

Electromagnetic/Electrothermal Gun Technology

"Last year, the committee encouraged the Army to accelerate its efforts to demonstrate the potential of electromagnetic and electrothermal gun technology for tank and artillery applications. The Army conducted a series of tests that demonstrated the theoretical potential of electrothermal gun technology. But those tests also revealed substantial areas of technical and engineering uncertainty in turning that technology into weapons.

Last year, the Army was arguing that it had to field a new generation tank by 1997 because of the pace of modernization in the Soviet/Warsaw Pact threat. That modernization schedule effectively precluded the introduction of electrothermal guns. The developments of the past year have removed the urgency to meet an artificial deadline. The committee believes that there is now time to incorporate the most promising technology in the next tank and artillery systems.

For those reasons, the committee recommends an increase in authorization of $20 million to continue research and development on electrothermal gun technologies."

2. Senate Appropriation Bill, 1991, No. 961, Report 101-521:

Weapons and Munitions Technology

"As explained in the Committee's discusison of the block III tank, the Committee recommends an increase of $10,000,000 for electrothermal gun research and development."

3. Senate Appropriation Bill, 1991, No. 961, Report 101-521:

Block III Tank

"The Committee's recommendations emphasize, instead, fundamental technology developments for the next generation of tanks and ammunition improvements to upgrade the lethality of the M-1 series. The Committee has added $12,000,000 for development of electrothermal chemical and electromagnetic gun technologies and solid-state switches and capacitors required for this technology."

APPENDIX D

Electric Armament Program Update
Gregory E. Ferdinand

ELECTRIC ARMAMENT PROGRAM UPDATE

Gregory E. Ferdinand
Chief, Electric Armament Program Office
U.S. Army Armament Research, Development and Engineering Center

INTRODUCTION

On June 12, 1989, a review of the Army's Advanced Propulsion Programs was conducted by the Commanders of the Army Material Command and Training and Doctrine Command. As a result of that review, the leadership approved the presented electric armaments program strategy and directed that a Program Office, located at the Armament Research, Development and Engineering Center (ARDEC), be formed to provide focus and coordination for all tactical electric gun programs within the Army.

On 23 August 1989, the Mission and Functions Statement for the Electric Armaments Program Office (EAPO) was approved by the Commanding General, ARDEC. Interim staffing of EAPO was accomplished on October 22, 1989. The primary responsibility vested in EAPO through its Mission Statement was to manage the Electric Armament Program Strategy and to coordinate the Army program throughout the technical community.

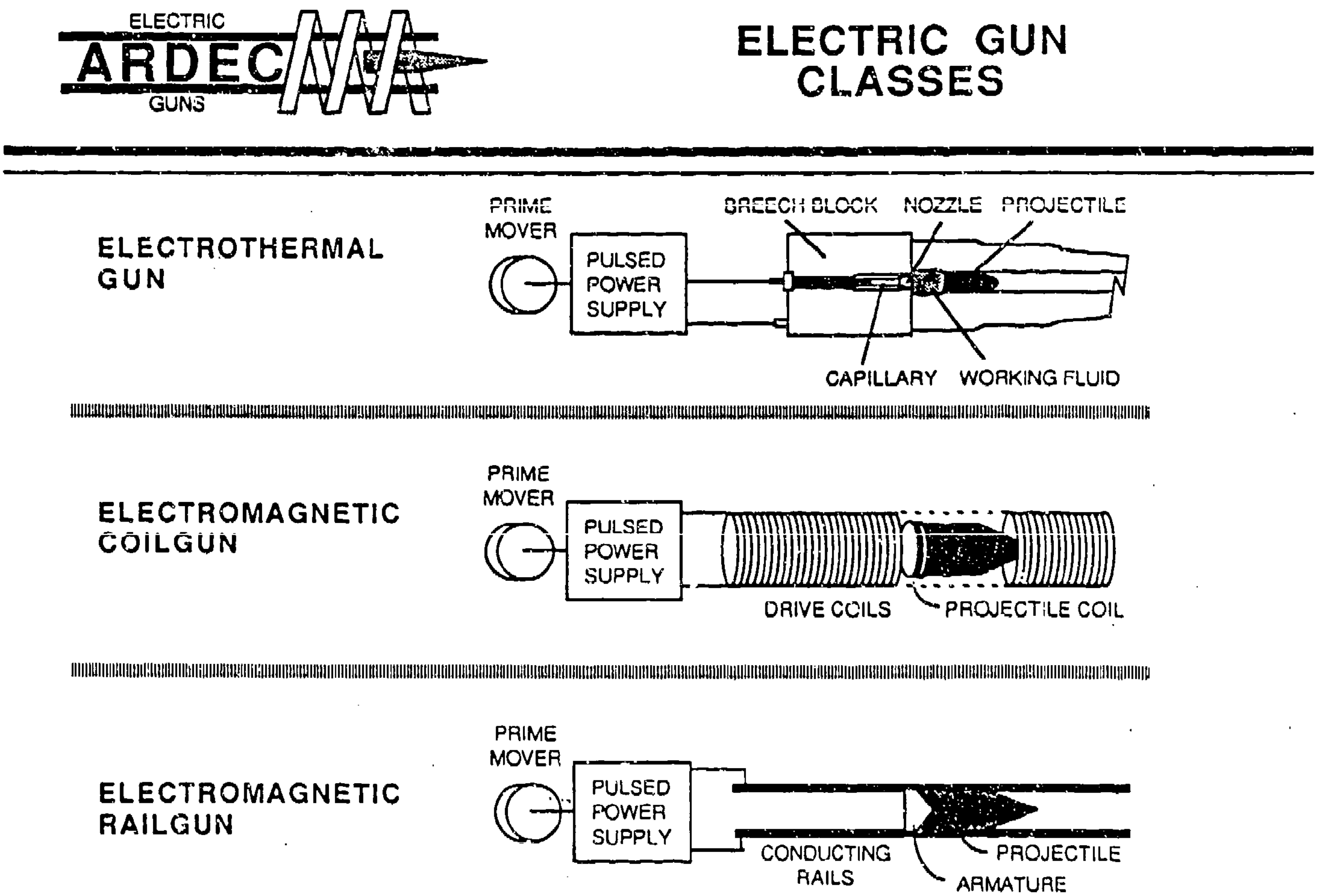
Over the intervening year, EAPO has made significant progress in creating an infrastucture to execute the Army Program, and, through that infrastructure, has ensured the integration of the Army Program throughout the technical community. In addition, changes to the Army Program strategy have been introduced by EAPO as a result of its assessment of technical progress, fiscal reality and Congressional direction.

PROGRAM STATUS

GENERAL

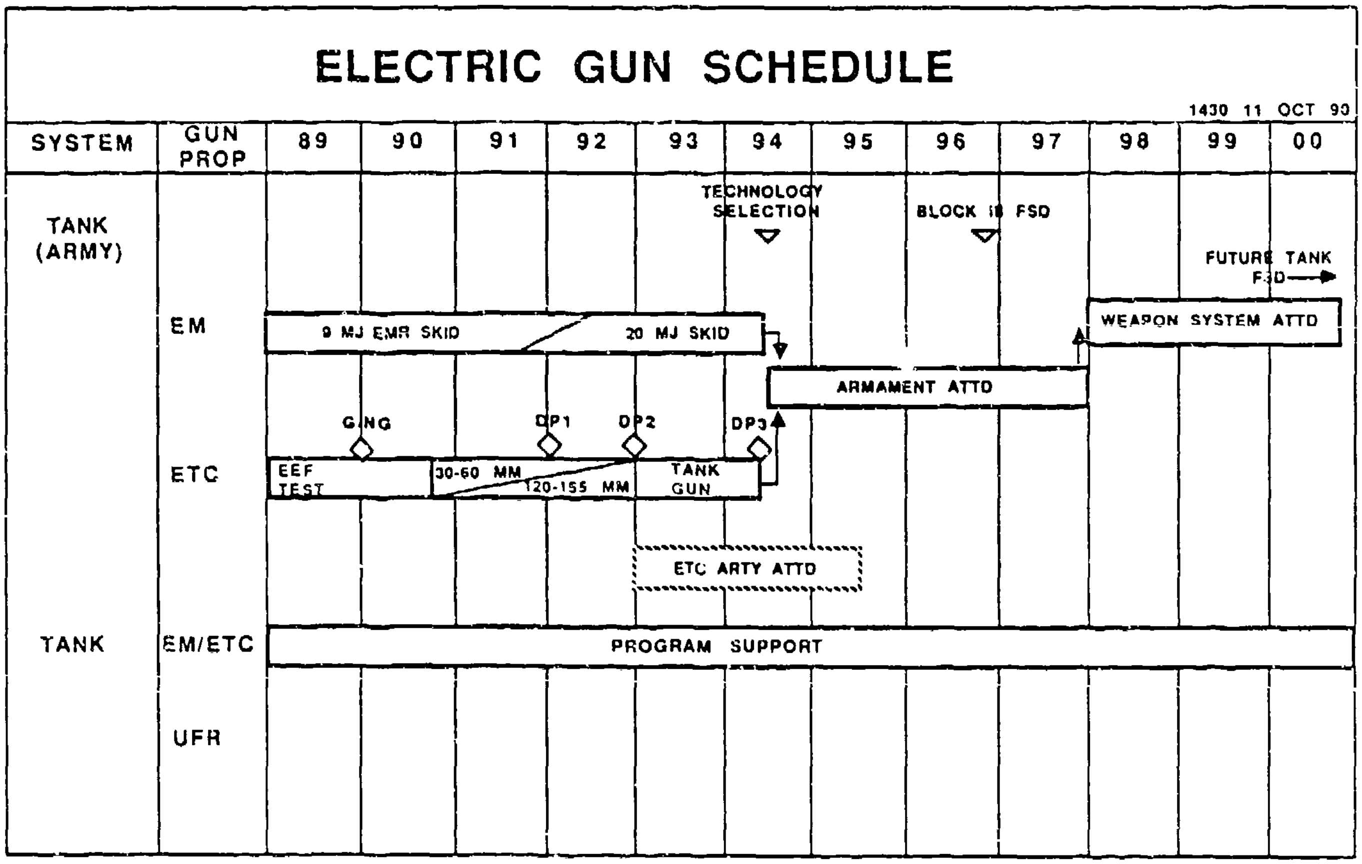
At the time this Panel conducted its initial review the Army Program was focused on Electrothermal Chemical Propulsion (ETC) and two forms of Electromagnetic Propulsion. . . railguns and coilguns (Figure 1). By virtue of the near-term maturation promised by its advocates, the ETC propulsion program led the electromagnetic propulsion programs by three years. The Army strategy in Electromagnetic propulsion competed coilgun technology against railgun technology for a downselect in FY91.

Figure 1.



Over the intervening year, changes have been introduced which effected the cancellation of the coilgun program and shifted the ETC propulsion timeline three years to the right. These revisions are reflected in the current Program Strategy presented as Figure 2. A discussion of the revised program is provided below.

Figure 2.



COILGUN

Sponsorship of the coilgun program was conducted under the Balanced Technology Initiative which is a special Congressional program administered by OSD. As a result of a restructure within the BTI program, all FY90 funding for the coilgun effort was withdrawn by the Director, BTI. This action reduced the Army electromagnetic gun program to the railgun option only.

ELECTROTHERMAL CHEMICAL PROPULSION

At the time of the Panel's initial review, electrothermal chemical propulsion was considered by its advocates to hold great promise for near-term weaponization. In order to test that premise, the Army, with encouragement from Congress, conducted a series of experiments at the Green Farm Test Range, on Miramar Naval Air Station. Through these experiments, the Army demonstrated that the technology was not as near-term a prospect as many of its advocates had believed. In recognition of those results, the strategy for ETC propulsion was revised. As now configured, ETC and EM technology are in direct competion with one another. Providing they both continue to show promise, ET and EM will continue maturation through mid FY94. At that point, a selection of the most promising technology will be made and that technology will continue to be developed for an Advanced Technology Transition Demonstrator (ATTD).

To mitigate additional disappointment in the venue of ETC Propulsion, the Army has integrated technical off-ramps in its program. Specifically at the end of FY91, FY92 and FY93 reviews will be conducted to determine if the technology has kept pace with established progress criteria. These criteria are referred to as Decision Points 1-3 in figure 2 and discussed at length in Decision Point Criteria extracted from Ballistic Research Laboratory Memorandum of Understanding, Appendix F.

Furthermore, in recognition of the limited understanding of the interior ballistic process demonstrated through the Green Farm experiments, the ETC Propulsion program now places greater emphasis on the concurrent development interior ballistic codes, diagnostics and modeling. Through the revised program, the initial portion of these efforts are being undertaken in smaller calibers and then brought to test in the calibers of interest. As an adjunct to the above, the Defense Nuclear Agency has also initiated an effort in ETC diagnostics and modeling (see related activities below). The Army program will leverage that effort through collaborative activity.

Finally, the Army Program has incorporated a contractual effort designed to identify, formulate and test alternative "working fluids" for ETC cartridges. This effort is coordinated
with the ETC contractors through the Army's Ballistic Research Laboratory (BRL).

The technology focus of the Army's Program continues to be in the area of direct fire tank main armaments. Through its ETC contractors, the Army is, however, assessing the technology for applicability to indirect (artillery) systems as well. It should be noted that funding for a future artillery ATTD is no longer carried in the POM. Should the technology demonstrate potential in this area, it is expected that funding for that ATTD will be restored.

ELECTROMAGNETIC RAILGUN PROPULSION

Steady progress has been made in the development of an electromagnetic railgun. The basic physics for this technology are less complicated and more understood than for ETC propulsion. However, the engineering problems are very difficult.

To solve these problems, a strategy of successively more challenging armament demonstrations has been planned. At the end of FY91, a 9 Mega Joule (MJ) muzzle energy, self-contained, transportable railgun is to fire at Yuma Proving Ground. This effort will be followed by a 20 MJ demonstrator scheduled for test firings at the end of FY93.

The EM program will continue maturation through mid-FY94. At that point, a selection between EM and ETC will be made and the most promising technology will continue to be developed for an Advanced Technology Transition Demonstrator (ATTD).

The technology focus is on anti-tank applications. No demonstrations are planned for artillery or air defense missions. Nor are any electromagnetic propulsion alternatives to railguns being pursued due to funding constraints.

PULSE POWER TECHNOLOGY

Very difficult problems in energy generation, storage and transmission have been successfully addressed by the Electric Gun Program. Specifically, advancements in high energy density batteries and high power density capacitors have been remarkable. These devices will have wide applicability throughout the Army, but particularly in Directed Energy Weapons programs.

Another area of great advancement has been in using rotating machines for energy storage. Specifically, the compulsator developed by the University of Texas promises higher specific energies than battery/capacitor systems. The compulsator will power the 9 MJ railgun scheduled to fire at the end of FY91 and is expected to be part of the 20 MJ demonstrator test at the end of FY93.

Overall, past power source development strategy, although highly successful, has centered on developing isolated components. The first attempt at integrating batteries, capacitors, pulse forming networks and generators in a transportable, multi-Mega-Joule Pulse Power Module (PPM) for ETC guns is being undertaken through the Army BTI Program. The PPM, which is the centerpiece of this effort, is contracted to FMC. Scheduled for delivery to Yuma Proving Ground in October 1993, this self-contained system will demonstrate repetitive firing for large caliber ETC based systems.

RELATED ACTIVITIES

JOINT ELECTRIC ARMAMENTS COMMITTEE

In response to Congressional Language in the FY89 Defense Authorization Conference Report, the OSD office of Research and Advanced Technology conducted a Topical Review of Electric Armament Programs throughout the Department of Defense. Emerging from that review, was the creation of a Joint Electric Armaments Committe (JEAC) with constituency from DARPA, DNA, SDIO, Navy, Air Force and Army. By charter, the JEAC will report to the OSD DDR&E. Chairmanship of the JEAC will reside with the Army.

By virtue of its experience in related technology, the Defense Nuclear Agency (DNA) has established a complementary program in ETC modelling/diagnostics. Through the JEAC and joint program reviews, the Army program will leverage that activity to support its initiatives in the area above.

In consonance with the above review, the Army decision to establish Yuma Proving Ground, Arizona, as a national test site for electric guns was sustained. Facilitization of Yuma Proving Ground in scheduled to begin this year.

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTER (FFRDC)

On 25 May 1990 ARDEC placed a contract with the Institute for Advanced Technology (IAT) establishing an FFRDC to perform basic research in the areas of pulse power and hypervelocity physics. Both of these areas are included in the DoD Critical Technology Listing (Reference 22).

COORDINATION/COLLABORATION

Through EAPO, the Army has developed an infrastructure to optimize coordination and collaboration within both the Army and the technical community at large. As part of this effort, Memoranda of Understanding (MOU's) have been executed with the Ballistic Research Laboratory, the Electronics Testing & Devices Laboratory and the Defense Nuclear Agency. Through these memoranda collaborative and coordinative relationships have been formalized. Additionally, in a less formal vein, the Army has also initiated a process of Joint Program reviews with the Air Force, Army Strategic Defense Command, DARPA and the Navy. Through its chairmanship of the JEAC, the Army is planning on moving toward more structured and more formal collaborative initiatives.

INTERNATIONAL PROGRAMS

The Army has continued to search for beneficial collaborations to bring additional resources and talent to bear on challenging problems. A brief summary of ongoing activities in this area is provided below.

__Israel:__ A collaborative research and development effort in solid propellant ETC has been initiated with Israel. Through this program the Army is attempting to mitigate the risks associated with the "fluid" approaches being taken by its contractors.

__United Kingdom:__ The Army is the Executive Agent for DARPA's collaborative program with the UK. This program is focused on developing saboted projectiles for railguns as well as establishing facilities for the testing of these projectiles.

__Germany:__ At the time of the last report, the US and Germany were considering initiation of a joint program in electrothermal chemical propulsion and the development of projectiles for those systems. Due to the political upheaval which enveloped Germany (reunification), the creation of European Community 92 and the EUCLID, that opportunity was lost. Recently however, the Army has participated in preliminary discussion with Germany designed to resurrect a cooperative effort in electric armaments circa FY92. The focus of that program is yet to be determined and will be the subject of discussions planned for March, 1991.

__France:__ The Army is currently pursuing the possibility of a cooperative agreement with France in the coilgun area. In March 1990, LABCOM representatives presented a preliminary ARDEC cooperative coilgun program proposal at the 5th U.S./France Technology Working Group. U.S. contribution was proposed to be $15M over five years, with the French contribution to be determined. Initial French reaction was positive. When a structure is defined, the program will be a candidate to become a Nunn cooperative program. The vehicle for initial discussions would be the Electric Gun Annex to Master Data Exchange Agreement Between U.S. and France. The Annex is in DA approval stage.

__Japan:__ Though there currently is no cooperative electric armament program with Japan, the OSD Topical Review has recommended that this be assessed following reciprocal survey visits of technical experts.

CONCLUSION

In pursuit of its mission to become the focal point for the Army, the Armament Research, Development and Engineering Center (ARDEC) has made significant progress over the last year. Through the establishment of the Electric Armaments Program Office, a centralized management structure for ensuring coordination throughout the technical community has been created. Specifically, interfaces with the Navy, Marine Corps, Air Force, Defense Nuclear Agency, Defense Advanced Research Projects Agency and the Department of Energy are maintained. The Electric Armaments Program Office is also the focal point for related international research and development programs.

APPENDIX E

ETC Propulsion Performance Criteria

MEMORANDUM FOR RECORD

SUBJECT: DP1 & DP2 Criteria

DATE: 25 July 1990

I. BACKGROUND:

1. In the overall Army Electric Gun Strategy, ETC gun propulsion technology through the end of FY92 is to focus on development of ETC technology to support to support a rational decision on the continued development of this technology and its application in an artillery ATTD beginning in FY93 and a tank ATTD beginning in FY95. Experimental gun firings for the program are to be performed in full-scale (120mm and/or 155mm) and sub-scale (30mm - 60mm) caliber. In the initial phases of the program, it is expected that the majority of firings will be performed in sub-scale diagnostic fixtures, transistioning primarily to full-scale firings during FY92.

2. In order to monitor ETC technology development and be able to answer pertinent questions related to this propulsion concept in order to determine the viability of the technology relative to a tank and/or artillery ATTD by the end of FY92, specific propulsion performance criteria have been established together with a timetable by which the criteria must be met. The specific propulsion performance criteria and schedule are referred to as Decision Point 1 (DP1) and Decision Point 2 (DP2) in the ETC Program Schedule, see Enclosure 1. DP1 is presently scheduled to occur at the end of FY91 and DP2 at the end of FY92.

3. Under the current plan, each contractor will be allowed to develop their specific ETC concept for tank and/or artillery applications at least through DP1. At the first decision point, DP1, the contractor's performance against the DP1 criteria will be determined. If the contractor's performance satisfies the DP1 criteria for both tank and artillery, then the contractor will proceed with technology development of their ETC concept to meet the DP2 criteria pertaining to both tank and artillery applications. However, if the contractor's performance at DP1 satisfies only the criteria related to one of the applications (tank/artillery), their concept would only be considered through FY92 and evaluated at DP2 for that application.

II. TERMINOLOGY: The meaning of several terms used in the DP1 and DP2 criteria are given below. See sections III and IV for additional details and specific performance required.

1. Performance Improvement: For DP1, performance improvement will refer to an increase in projectile muzzle kinetic energy over the muzzle kinetic energy computed from an optimized solid propellant calculation (propellant grain geometry and mass varied to produce maximum muzzle velocity) with the ballistic parameters, chamber volume & geometry, bore diameter and projectile mass and travel, provided by the contractor for the experimental test fixture selected by the contractor to demonstrate the DP1 criteria. Details concerning projectile masses to be utilized in sub-scale fixtures are provided in section III. The simulations will be performed by BRL using the interior ballistic computer code IBHVG2 and the chambrage gradient. The maximum chamber pressure for the tank simulation will be 575 MPa and for the artillery simulations 330 MPa. In performing the simulations, heat loss and shocked air in front of the projectile will be considered. Shot start pressure and bore resistance profile will be that used at BRL to simulate the M829 120mm round for tank applications and the M864 round for artillery applications. The maximum propellant loading density allowed in the simulations will be 1.1 g/cm^3. The solid propellants used in the simulations will be those currently used in fielded tank 120mm rounds or fielded 155mm artillery rounds and developmental propellants whose end application is projected for tank or artillery applications in the same time frame that an ETC weapon is projected to become operational (BLOCK IV for tank, date of down selection between ETC and Uni-charge/LP FY91 down select candidate). Thermochemical properties of the solid propellants will be those computed by the thermodynamic code BLAKE. Current solid propellant candidates are JA2 for tank applications and M30 for artillery applications. The reference muzzle energy will be the maximum value computed using the appropriate solid propellants for each weapon application. There will be a value for tank applications and a value for artillery.

For DP2, performance improvement will refer to an increase in muzzle kinetic energy over computed muzzle kinetic energy obtained as described in the previous paragraph, except that the gun dimensions will be for the M256, 120mm tank cannon and the 52 caliber, 155mm artillery cannon. Alternatively, specific muzzle kinetic energy levels to be demonstrated by the contractor could be specified by the Army.

2. Repeatability: Repeatability will be defined in terms of one standard deviation in muzzle velocity for 10 consecutive firings all of which have the same configuration (electrical energy, working fluid and projectile mass, plasma generation configuration, etc.). For repeatability in sub-scale fixtures, the velocity is to be measured at 50 calibers of projectile travel. The 10 firings must be identified prior to their performance and witnessed by a government representative. Test conditions for each shot will be recorded, i.e. projectile mass, charge mass, etc. Efforts must be made to minimize variations in these parameters. Accuracy/precision requirements of the pressure and velocity measurement system will be established prior to firing a repeatability test series. Measurement system accuracy must exceed the requirements specified by the criteria. That is, if one standard deviation in velocity must be less than 0.5%, then the measurement system must be accurate to less than 0.5%.

3. Process Control: Process control refers to the ability to predictably alter pressure rise rate, maximum chamber pressure and width of the pressure vs. time profile (pulse duration). Process control reflects an understanding or knowledge of the ETC interior ballistic process and the ability to design developmental ETC cartridges which may ultimately meet military requirements for safety, reliability, performance, etc.

   Pressure rise rate is defined as the maximum value of dP/dt of the breech pressure versus time curve during the pressure rise from 20% to 90% of maximum pressure.

   Pulse duration or width of the pressure versus time profile is defined as the width in milliseconds of the breech pressure versus time curve measured at two-thirds (2/3) of maximum pressure. If oscillations or waves are present in the breech pressure versus time curve such that a line parallel to the time (horizontal) axis at two-thirds of maximum pressure intercepts the pressure versus time curve in more than two locations, then the pulse duration will be defined as the length in milliseconds of the longest secant line segment which is a portion of this line (see figure below).

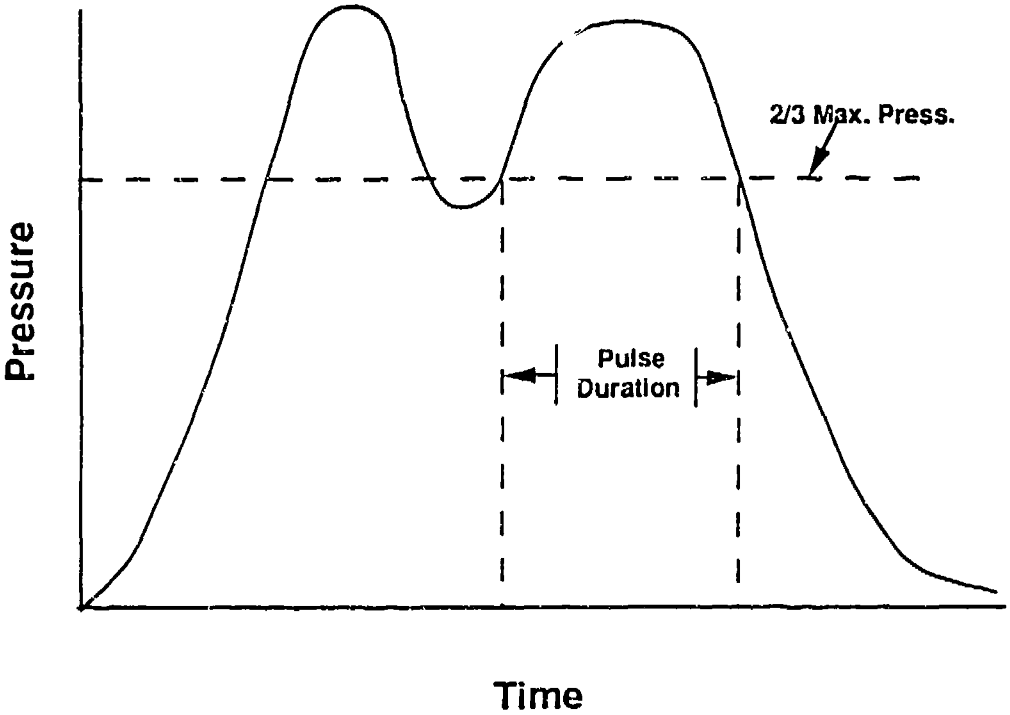


Figure 1. Pulse Duration For P Vs t Profile With Oscillations

4. Predictability: Predictability is defined to be the difference between computer predictions and experimental results. For the DP1 and DP2 criteria the computer predictions must be performed prior to the experimental firing. Three differences between computer predictions and experimental results will be utilized; maximum breech pressure, projectile muzzle velocity and breech pressure versus time profiles. For the later, the difference between predicted and experimental pressure at each time step of the experimentally recorded data is the measurement of interest. The zero point in time for experimental data will be based upon the beginning of projectile motion. From the computer prediction, the time interval (number of milliseconds) from ignition to start of projectile motion is known. Subtracting this same time interval from the time of the start of projectile motion in the experimental data will define the zero point for the experimental data. In determining maximum experimental breech pressure and the difference between predicted and experimental pressure the experimental pressure to be used is the mean filtered pressure data. The government will determine the filter characteristics to be applied to each firing. This does not imply that the presence of pressure oscillations/waves are to be ignored. All pressure versus time profiles are to be provide to the government without filtering. The purpose

for filtering the data is to provide a clear method for determining the maximum pressure and the value of experimental pressure to use in the pressure difference.

5. Frequency response refers to the total frequency response of the recording system.

III. DP1 Criteria: The criteria consists of two components. One portion is based upon experimental gun firings (actual performance or comparisons with computer predictions) the second, reports addressing key issues for the technology. All DP1 criteria must be addressed on or before the DP1 date which currently is the end of FY91 (30 September 1991).

Component I: Experimental Firings

1. The contractor is to demonstrate in an ETC gun of a caliber selected by the contractor (minimum caliber 30mm); with gun dimensions scaled for the appropriate application; utilizing a working fluid selected by the contractor (current or alternate working fluid); with a round configuration (pumped or cased) planned for DP2 and the ATTD, and with a projectile scaled for either tank and/or artillery application; the following:

Note 1: For sub-caliber testing, experimental parameters such as projectile mass, projectile travel, chamber volume and working fluid/charge mass must be consistent with the end application, tank or artillery. The intent is not to have contractors design and fabricate several different sub-caliber fixtures but to scale chamber volume, working fluid/charge mass and projectile mass to be consistent with a tank/artillery application. For example, one possible method for scaling the projectile mass is to scale by a factor which is the cube of the ratio of the sub-scale caliber to full-scale caliber. The baseline projectile for the tank is 11.4 kg and for artillery 46.7 kg. The scale factor is the third power of the ratio of ETC experimental gun caliber to 120 or 155, depending on the intended application. For a 30mm test fixture; ratio $= (30/120)^3 = 1/64$, scaled tank projectile mass = 178 g, scaled artillery projectile = 339 g. In meeting the DP1 criteria, the government must approve whatever approach to scaling is being used by the contractor.

Note 2: The projectile used to demonstrate the DP1 criteria may have either a flat base or intrude into the chamber.

a. Performance Improvement: 15% increase in muzzle kinetic energy compared to the muzzle energy computed in the simulations performed by BRL as described in Section II 1. above. Experimental firings using scaled tank projectiles will only be compared to the baseline muzzle energy computed for the tank application. Firings using scaled artillery projectiles will only be compared to baseline muzzle energy computed for artillery application.

Note: Target muzzle energy as computed by BRL for each application will be provided to the contractor within 30 days after receipt of the necessary dimensions of the experimental fixture. See Section II 1.

b. Repeatability:

One Standard Deviation in velocity must be less than 0.5%. This value is to be obtained for a series of firings as specified below for each application.

Tank: One set of 10 consecutive firings utilizing the initial conditions for the gun firing used to demonstrate the performance improvement in Section III 1.a. for the tank application. If the performance improvement required by Section III 1.a. is not obtained, then the initial conditions for the 10 gun firings for the repeatability series shall be that used in obtaining the largest experimental performance improvement for the tank application obtained by the contractor.

Artillery: Two sets of 10 consecutive firings are required as described below.

One set of 10 consecutive firings utilizing the initial conditions for the gun firing used to demonstrate the performance improvement in Section III 1.a. for the artillery application. If the performance improvement required by Section III 1.a. is not obtained then the initial conditions for the 10 gun firings for the repeatability series shall be that used in obtaining the largest experimental performance improvement for the artillery application.

One set of 10 consecutive firings utilizing the initial conditions for the gun firing used to demonstrate the performance improvement in Section III 1.a. for the artillery application adjusted as determined by the contractor to obtain a maximum breech pressure of 210 MPa. If the performance improvement required by Section III 1.a. is not obtained then the initial conditions for the 10 gun firings for the repeatability series shall be that used in obtaining the largest experimental performance improvement for the artillery application adjusted as determined by the contractor to obtain a maximum breech pressure of 210 MPa.

c. Process Control: Predictably alter pressure rise rate, maximum chamber pressure and pulse duration as indicated below.

Note 1: The contractor, with concurrence of the government, will determine a set of initial conditions for an ETC firing which will define the nominal values to be altered. Nominal values shall be consistent with the method of scaling and overall ballistic action time selected by the contractor.

Note 2: Only one parameter, pressure rise rate, maximum pressure or pulse duration needs to be altered per firing.

Alterations for both tank and artillery:

Pressure Rise Rate: +20% and -20% of nominal value
Maximum Chamber Pressure: +20% and -20% of nominal value
Pulse Duration: +15% of nominal value

d. Predictability: For the repeatability series in Section III 1.b. and the process control firings of Section III 1.c. computer predictions must be provided prior to the series of firings which match the experimental results as indicated below.

Maximum Chamber Pressure < 5%

Muzzle Velocity < 2%

Breech pressure verse time curve comparison: Difference between experimental pressure (Section II 4.) and predicted pressure not to exceed 10% of the predicted breech pressure for any time step.

Component II: Reports

2. Prepare detailed reports addressing:

a. Zoning (if applicable): Present zoning concept for review. The concept will be reviewed by a government review panel which will judge the suitability and viability of the zoning concept relative to development and ultimate fielding.

b. Pressure Oscillations/Waves: Address the impact that any experimentally observed pressure oscillations and/or waves will have on the ballistic process, especially on projectiles. In this report the term "address" implies that the contractor will "judge/provide an opinion" on what impact pressure oscillations/waves will have on the process including possible physical damage to the projectile and gun system. The report should present a plan to investigate suppression methods to eliminate/minimize oscillations/waves in subsequent technology development.

c. Working Fluids: Demonstrate that viable working fluid alternatives have been identified and are being developed. It is the responsibility of the contractor to identify at DP1 the working fluid to be used in satisfying the DP2 criteria. It is the responsibility of the contractor to provide data required by the Army in the following areas:

Formulation: candidate assessment based on thermochemical and interior ballistic analysis. Evaluation of the physical and chemical properties of the formulation with respect to suitability to the weapon environment. Preliminary specifications for the formulation with allowable impurity levels, processing description and compatibility data.

Chemical Analysis: Identification of analytical techniques used and suggestions for further developments needed for formulation quality control.

Toxicity: Preliminary review and evaluation of available data and suggestions for further work to assess health hazards based on probable use scenario.

Environmental Impact: Preliminary evaluation to determine potential implications of fielding including demilitarization and disposal, and regulatory impacts of manufacturing, shipping and use of candidate working fluids.

Safety and Storage: Data needed for interim hazard qualification of candidate working fluids based on TB700-2 tests. Data relative to storage compatibility class and long term physical and chemical stability.

Vulnerabiliy: Data relevant to the requirements of draft MIL-STD 2105A.

Physical Properties: Available data on key physical properties of candidate working fluids to include density, viscosity compressibility, surface tension, sound speed, ratio of specific heats, vapor pressure, compression sensitivity, freezing and boiling points, thermal conductivity, gas solubility, electrical conductivity and dielectric properties as a function of temperature and pressure where appropriate.

Producibility: A priliminary assessment of producibility of candidate working fluids including estimates of unit cost, availability of ingredients and facilitization requirements.

The referenced documentation can be obtained from ARDEC AED within 30 days of contract award.

d. System Impact: Determine, based upon either sub-scale or full-scale firings, the electrical energy required to meet the ballistic requirements of DP1 in 120mm and/or 155mm. Based upon data supplied by the Electric Armaments Division, ARDEC determine size and weight of required power supply. Identify potential show stoppers relative to system integration which are felt to require additional technical development.

e. Residue: If residue is observed after gun firings, provide pictures of residue and particle size.

f. Barrel/chamber wear and erosion.

g. Temperature sensitivity.

IV. DP2 Criteria: As with DP1, the criteria consists of two components. All DP2 criteria must be addressed on or before the DP2 date which currently is the end of FY92 (30 September 1992).

Component I: Experimental Firings

1. The contractor is to demonstrate in an ETC gun of the appropriate caliber for the tank (120mm M256 cannon) or artillery (155mm 52 caliber Cannon); utilizing a viable working fluid determined by the contractor; with a round configuration (pumped or cased) planned for an ATTD, and with a projectile appropriate for the either tank or artillery applications; the following:

a. Performance Improvement: Satisfy either (1) or (2) as specified by the Army.

(1) A 35% increase in muzzle kinetic energy for the appropriate application compared to the muzzle energy computed in the simulations performed by BRL as described in Section II 1. above.

(2) Specific muzzle kinetic energy for tank and/or artillery as determined by the user community within the Army.

Note: Target muzzle energy for each application will be provided to the contractor by 31 October 1991. For planning purposes the upper limits for muzzle energy to be obtained with ETC propulsion are 17 MJ for tank and 33.6 MJ for artillery.

b. Repeatability & Zoning:

Tank: One Standard Deviation for velocity < 0.35% obtained for one set of 10 consecutive firings utilizing the initial conditions for the gun firing used to demonstrate the performance improvement in Section IV 1.a. for the tank application. If the performance improvement required by Section IV 1.a. is not obtained then the initial conditions for the 10 gun firings for the repeatability series shall be that used in obtaining the largest experimental performance improvement for the tank application.

Artillery: Three sets of 10 consecutive firings are required. The three sets are to correspond to performance levels associated with the low, a medium and top zone required for artillery. The top zone is defined as that performance level demonstrated in Section IV 1.a.

Low Zone: One Standard Deviation for velocity < 0.25% obtained for one set of 10 consecutive firings utilizing initial conditions designed to obtain low zone artillery performance.

Medium Zone: One Standard Deviation for velocity < 0.25% obtained for one set of 10 consecutive firings utilizing initial conditions designed to obtain a medium zone artillery performance level. The specific zone will be specified by the Army by 31 January 1992.

Top Zone: One Standard Deviation for velocity < 0.25% obtained for one set of 10 consecutive firings utilizing the initial conditions for the gun firing used to demonstrate the performance improvement in Section IV 1.a. If the performance improvement required by Section IV 1.a. is not obtained then the initial conditions for the 10 gun firings for the repeatability series shall be that used in obtaining the largest experimental performance improvement for the artillery application obtained in Section IV 1.a.

c. Predictability: For the repeatability series in Section IV 1.b. computer predictions must be provided prior to the series of firings which match the experimental results as indicated below.

Maximum Chamber Pressure < 2%

Muzzle Velocity < 1%

Breech pressure verse time curve comparison: Difference between experimental pressure (Section II 4.) and predicted pressure not to exceed 10% of the predicted breech pressure for any time step.

d. Pressure Oscillations and/or Waves: For the firings of Section IV 1.a. and 1.b. document what affect that any observed pressure oscillations and/or waves have had on projectile integrity or on internal or external gun components. This should include flash X-ray of the projectile and examination of the gun chamber, tube, etc. by representatives of Benet Weapons Laboratory.

Component II: Reports

2. Prepare detailed reports addressing:

a. Zoning (if applicable)

b. Pressure Oscillations and Waves

c. Working Fluids: Provide necessary data which would satisfy Army requirements for a fieldable propellant as partially defined in III.II.2.c.

d. System Impact: Determine the electrical energy required to meet ballistic requirements of DP2. Based upon data supplied by the Electric Armaments Division, ARDEC determine size and weight of required power supply. Provide conceptual design for an appropriate weapon system, tank or artillery, for which the DP2 criteria has been satisfied.

e. Other ballistic issues: Provide data based upon all gun firings in 120mm and/or 155mm ETC guns which address the issues of:

- Gun chamber/tube wear & erosion
- Barrel life & fatigue
- Temperature sensitivity (actual gun firings must be performed in the temperature range of -55 F to +155 F)
- Signature
- Heat transfer and cook-off

REVIEWED BY:

BRL	ARDEC
Dr. I. May	Mr. B. Knutelsky
Dr. W. Morrison	Dr. K.C. Pan
Mr. A. Horst	Dr. L. Harris
Dr. J. Rocchio	Mr. J. Hedderich
Mr. B. Burns	
Dr. A. Juhasz	
Dr. K. White	
Dr. T. Minor	
Mr. G. Katulka	
Mr. J. Knapton	
Mr. I. Scobie	
Ms. G. Wren	
Mr. W. Oberle	

APPENDIX F

Alternative Electromagnetic Gun Concepts

ALTERNATIVE ELECTROMAGNETIC GUN CONCEPTS

EM guns have the important advantage that the interaction of electromagnetic forces with projectiles is well understood and amenable to mathematical modelling; therefore, analysis can be used to determine the optimum match between the propulsion and the energy conversion equipment. Unfortunately, this is not the approach being followed by EM guns developers. For reasons not clearly understood, only two types of projectile developments were initially considered, the railgun and the coilgun. Then all developers embraced the railgun, and the benefits of the coilgun and other contenders were lost.

The coilgun may be thought of as a series of these solenoids that each impart a thrust to the base of the projectile as it passes the end of each solenoid. The magnetic field appears to travel down the barrel, pushing on the base of the projectile as it proceeds. Sandia National Laboratory (SNL) is investigating this approach for launching payloads from earth to orbit (Reference H).

There are many variations of the coilgun, some of which involve using brushes to induce current in the base of the projectile. Brushes tend to produce sparks and arcs that reduce efficiency, and coupling with currents induced by alternating fields, can also be inefficient. However, today there are very efficient synchronous motors and generators, and motors and generators using brushes, but the restrictiveness of the railgun has not allowed all of these electrical engineering techniques to be explored.

Another accelerator that used to be found in plasma physics laboratories was the conically shaped solenoid that would propel a spherically shaped conductor by inducing currents in it as the coil was activated. The induced current than interacted with the field of the solenoid to accelerate it down the axis of the "wine glass" shaped solenoid. This is the force commonly used in solenoidal switches. By studying these alternate approaches to propelling projectiles, then we are likely to find that the energy conversion problem becomes less challenging, and the entire process can be done more efficiently with less weight and space. Unquestionably, there is a need for new ideas for propelling projectiles with electromagnetic fields, and for providing power in an optimum fashion. New ideas should be actively solicited through every possible channel; e.g., the Small Business Innovative Research (SBIR) program.

APPENDIX G

Coil Gun Research at
Sandia National Laboratories
(Supplied by Sandia National Laboratories)

Coil Gun Research at Sandia National Laboratories

For the past 5 years, Sandia National Laboratories has pursued a coil gun development program for the purpose of technology demonstration. The types of systems under investigation are induction driven; that is, the armature current is induced, and there is no need for sliding electrical contacts between the launcher and projectile. The absence of this contact improves barrel lifetime and allows higher velocities. The launcher consists of many separate solenoidal coil stages that are closely spaced and separately energized by capacitor discharges initiated with closing switches. The armature is a solid or hollow metal armature that is simple and strong. The projectile position is measured during the launch and the coils fired sequentially as the projectile passes down the bore. A magnetic wave moves with the projectile and provides the magnetic pressure for acceleration. With such a system, it is possible to maintain a nearly constant acceleration for the entire launcher length. Ohmic heating of the armature is also reduced to acceptable levels by proper design, pulse duration, and timing of the stages.

Experimental systems have been built to test and verify the intended operation. Early experiments considered a plate projectile for SDI applications. A 14-stage launcher was built and tested in 1988 that accelerated 140 gm of aluminum to 1 km/s. During the past two years, we have concentrated on cylindrical systems and larger projectile masses. This cylindrical configuration is being developed to demonstrate the technology needed for an Earth-To-Orbit (ETO) launcher system supported by SDIO. We have built a 6-stage launcher that has launched 5 kg at 335 m/s and also 3.6 kg at 403 m/s. This launcher has about 50 shots on the same barrel and has been used to fire a volly of 8 shots in one day with ± 2.5% variation in final velocity. Another feature of this launcher is that it can be used to decelerate the armature in the bore, and we have demonstrated magnetic sabot separation using this technique. We have also built a much smaller cylindrical launcher to examine scaling and to validate models and have achieved 538 m/s with a small 11.2 gm aluminum projectile.

Since we do not have sliding contacts or plasma arcs present in our launcher, it is possible to predict launcher performance from first principles. We have developed a fast running, mesh matrix computer code that precisely predicts launcher performance without any adjustable parameters. This code has been compared with all our experimental results with very good agreement and used for design of future launcher systems such as ETO.

There are a number of important technical issues that remain. Most important is demonstration of high velocity operation. We are developing a reduced scale launcher for this purpose that is being designed to achieve 4 km/s with a 400 gm aluminum armature. The velocity can be extended to 6 km/s in future upgrades. Our plans are to complete this effort in about 2 years. The technical issues to be addressed are for the most part engineering. We must develop a high performance coil design that survives high mechanical forces, high voltage, and thermal loads. The projectile-wall interaction is also a concern as is barrel wear and plasma production in the bore. Although potentially significant, we expect these problems to be less serious for our coil gun than for guns that require a gas seal. Current technical efforts are directed toward space launch applications. The technology has potential for tactical applications, although these considerations are not part of the current program.

APPENDIX H

Conflict of Interest Review Text

DEPARTMENT OF THE ARMY
ARMY SCIENCE BOARD
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, D.C. 20310-0103

26 October 1989

Mr. Alvin R. Eaton
Senior Fellow
Director of Special Programs
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, Maryland 20707-6099

Dear Mr. Eaton:

Attached for your information is a copy of a memorandum from Mr. Ernest Willcher, Army Science Board (ASB) Ethics Counselor, dated 25 October 1989.

As you know the ASB has a procedure whereby the Office of the General Counsel reviews all Terms of Reference and associated participants lists for appearance of conflicts of interest. This process has been accomplished for the Army Science Board Ad Hoc Subgroup on Electro-Magnetic/Electro-Thermal Technologies.

Please note the two additional steps outlined in paragraph three of the attached memorandum.

a. First, as the panel effort develops, panel members should notify me of any potential conflict with any of their interests.

b. Second, the panel's report should include a statement by the panel chair either describing conflicts that have become apparent as a result of the panel's recommendations, or confirmation that there were no conflicts identified.

Your continued compliance with this procedure is appreciated.

Sincerely,

Thomas E. Stalker
LTC(P), GS
Executive Secretary

Attachment

DEPARTMENT OF THE ARMY
OFFICE OF THE GENERAL COUNSEL
WASHINGTON, DC 20310-0104

25 October 1989

MEMORANDUM FOR ADMINISTRATIVE OFFICER
ARMY SCIENCE BOARD

SUBJECT: Conflict of Interest Review

This responds to your 24 October 1989, memorandum, subject as above, concerning the Ad Hoc Subgroup on Electro-Magnetic/Electro-Thermal Technologies. We reviewed the terms of reference and participants' list, and we concluded that none of the panel members presently have apparent conflicts of interests. However, in light of their employment and financial interests, the members should pay particular attention to the suggestions in the last paragraph of this memorandum.

Our conclusion is based on application of the following test: Whether the matters before the panel are sufficiently specific as to lead to reasonable anticipation of financial interest. Applying this test, we consider the results of the panel's endeavors to be highly speculative, given the broad nature of the terms of reference before the panel. Accordingly, we cannot now reasonably anticipate that some advantage will accrue to any particular entity listed by the members.

To help assure the continued absence of any appearance of conflicts of interests, we suggest that two additional steps be taken. First, the members of the panel should be requested to notify the Army Science Board's Executive Secretary whenever their individual or collective efforts become more specific and they then perceive the possibility of a conflict with any of their interests. Second, the panel's report should include or be accompanied by a statement either describing any conflicts of interests that have become reasonably apparent as a result of the panel's recommendations or confirming that there are no such conflicts. Our office is always available to provide assistance in connection with these two steps.

The participant's files are returned herewith.

Ernest M. Willcher
Ernest M. Willcher
Attorney Advisor

Attachments

CF:
Dr. Thiele
Dr. Gourdine
Dr. Grum
Mr. Hubbard
Dr. Weinberger

APPENDIX I

List of Acronyms and Abbreviations

LIST OF ACRONYMS AND ABBREVIATIONS

ARDEC	Armament Research, Development and Engineering Center
ASB	Army Science Board
ATBM	Advanced Tactical Ballistic Missile
ATTD	Advanced Technology Transfer Demonstrator
BRL	Ballistic Research Laboratory
BTI	Balanced Technology Initiative
CEM	Center for Electromechanics (of The University of Texas)
DARPA	Defense Advanced Research Projects Agency
DEA	Data Exchange Agreement
DNA	Defense Nuclear Agency
DP1	Decision Point 1
DP2	Decision Point 2
EAD	Electric Armaments Division
EAPO	Electric Armaments Program Office
EEF	Enhanced Electrical Factor
EEGS	Electric Energy Gun Systems
EM/ET	Electromagnetic/Electrothermal
EMC	Electromagnetic Coil Gun
EMR	Electromagnetic Rail Gun
EMGWS	Electromagnetic Gun Weapon System
ETC	Electrothermal/Chemical Gun
ETO	Earth-to-Orbit
FFRDC	Federally Funded Research and Development Center
FMC	Food Machine Corporation
FSD	Full Scale Development
FY	Fiscal Year
hp	Horsepower
IAT	Institute for Advanced Technology (of The University of Texas)
JEAC	Joint Electric Armaments Committee
J	joules
J/m	joules/meter
Kg	kilograms
KJ/cc	kilojoules/cubic centimeter
Km/s	kilometer/second
LABCOM	US Army Laboratory Command
LP	Liquid Propellant
MJ	megajoules
MOU	Memorandum of Understanding
MPa	Megapascals
MW	megawatts

m/s	meter/second
nH/M	nanohertz/meter
OSD	Office of The Secretary of Defense
POM	Program Objective Memorandum
PPM	Pulse Power Module
R&D	Research and Development
RDTE	Research, Development Test and Evaluation
SBIR	Small Business Innovative Research
SDIO	Strategic Defense Initiatives Office
SNL	Sandia National Laboratories
EUCLID	European Cooperation for the Long Term in Defense
UK	United Kingdom
V/m	volts/meter
W/Kg	watts/kilogram
W/m	watts/meter

APPENDIX J

Letter from Study Chair

The Johns Hopkins University

Applied Physics Laboratory

Alvin R. Eaton
Senior Fellow
Director of Special Programs

February 27, 1991

Mr. George T. Singley III
Deputy for Research and Technology
Office of the Assistant Secretary
of the Army (RDA)
The Pentagon, SARD-ZT, Room 3E374
Washington, D.C. 20310-0103

Reference: "Electric Armaments Program Update," Presentation to George T. Singley III, by Gregory E. Ferdinand, Chief, Electric Armaments Program Office, dated 26 Feb. 1991

Dear Mr. Singley:

This letter is intended to provide an updated Army Science Board Panel summary evaluation of the revised Army Electric Armaments Program described in the reference presentation.

As you know, the 10 December 1990 "Final Report of the Army Science Board (ASB) Panel on Electromagnetic/Electrothermal (EM/ET) Gun Technology Development" strongly supported continuation of vigorous EM/ET research and development efforts, but was critical of the then-current program in several respects. In particular, it was concluded that realization of potential EM/ET benefits requires "additional emphasis on the illumination of fundamental issues, the maturation of component technologies, and the identification of innovative system applications;" that "performance demonstrations should be limited at this time to those essential to in-depth understanding of physical phenomena or program status" (minimizing large-scale demonstrations); that "the current lack of promise for ET technology should result in an orderly shifting (by the Army) of program and funding emphasis to other electric gun technologies;" that "power generation is still the critical technology for large-scale guns;" and that a "systems approach should be used to minimize engineering problems."

Johns Hopkins Road, Laurel, Maryland 20723-6099

Washington (301) 953-5000 Baltimore (301) 792-5000

During the past few weeks, extensive consultation has been carried out with principals in the Army program, with the result that significant program changes have been effected; those changes, as reflected in the reference, are responsive to, and entirely consistent with, the conclusions of the ASB Panel. In this connection, particular attention should be given to the "Before" and "After" "Funding Profile" incorporated in the presentation. As a consequence, as Chair of the ASB Panel, I would like to take this opportunity to indicate complete concurrence with the planned program.

May I also say that it has been personally gratifying to work with the many competent people who are associated with the Army's EM/ET technology development efforts. I do hope it will prove possible to provide them with the continuing, stable support needed to exploit the important technologies involved.

Sincerely,

Alvin R Eaton

Alvin R. Eaton, Chair,
Army Science Board Panel on
Electromagnetic/Electrothermal
Gun Technology Development

cc: Dr. A. Fenner Milton
Director of Technology, SARD-TT

Dr. Duane A. Adams
Chair, Army Science Board

APPENDIX K

LETTERS OF TRANSMITTAL TO CONGRESS

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

28 MAR 1991

The Honorable Sam Nunn
Chairman
Committee on Armed Services
United States Senate
228 Senate Russell Office Building
Washington, D. C. 20515-6018

Dear Mr. Chairman:

In the Senate Armed Services Committee Report #101-81, dated July 19, 1989, the Committee directed that the Army Science Board (ASB) monitor the Army's electromagnetic/electrothermal (EM/ET) gun development program during the subsequent two years and report progress in this technology to the Secretary of the Army. The Army was further directed to report the ASB findings to the Congress with the budget submissions for fiscal years 1991 and 1992.

The attached ASB report, "Electromagnetic/Electrothermal Gun Technology Development" is the second report provided in response to these Congressional directives. This year the special ASB panel which reviewed the Army's program found that EM/ET gun technology offers significant potential benefits to the Army but given recent test results is not ready for near term weaponization. In response to the report's conclusions, the Army's EM/ET program has been restructured to emphasize component maturation, the obtainment of a fundamental understanding of hypervelocity ballistics, and the exploration of innovative system concepts. Attached at the end of the report is a letter from Dr. Eaton, the ASB study chairman, supporting the Army's efforts to comply with the findings of the ASB study.

The additional funding provided by the 101st Congress for an enhanced Army EM/ET gun program is indicative of the enthusiasm shared by both government and industry for this exciting technology and its long term promise. The Army looks forward to your continued support.

Sincerely,

George

George T. Singley III
Deputy Assistant Secretary
for Research and Technology

Attachment

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

28 MAR 1991

The Honorable John P. Murtha
Chairman
Subcommittee on Defense
Committee on Appropriations
House of Representatives
Washington, D. C. 20515-6018

Dear Mr. Chairman:

In the Senate Armed Services Committee Report #101-81, dated July 19, 1989, the Committee directed that the Army Science Board (ASB) monitor the Army's electromagnetic/electrothermal (EM/ET) gun development program during the subsequent two years and report progress in this technology to the Secretary of the Army. The Army was further directed to report the ASB findings to the Congress with the budget submissions for fiscal years 1991 and 1992.

The attached ASB report, "Electromagnetic/Electrothermal Gun Technology Development" is the second report provided in response to these Congressional directives. This year the special ASB panel which reviewed the Army's program found that EM/ET gun technology offers significant potential benefits to the Army but given recent test results is not ready for near term weaponization. In response to the report's conclusions, the Army's EM/ET program has been restructured to emphasize component maturation, the obtainment of a fundamental understanding of hypervelocity ballistics, and the exploration of innovative system concepts. Attached at the end of the report is a letter from Dr. Eaton, the ASB study chairman, supporting the Army's efforts to comply with the findings of the ASB study.

The additional funding provided by the 101st Congress for an enhanced Army EM/ET gun program is indicative of the enthusiasm shared by both government and industry for this exciting technology and its long term promise. The Army looks forward to your continued support.

Sincerely,

George

George T. Singley III
Deputy Assistant Secretary
For Research and Technology

Attachment

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

22 MAR 1991

The Honorable Daniel K. Inouye
Chairman
Subcommittee on Defense
Committee on Appropriations
United States Senate
Washington, D. C. 20515-6028

Dear Mr. Chairman:

In the Senate Armed Services Committee Report #101-81, dated July 19, 1989, the Committee directed that the Army Science Board (ASB) monitor the Army's electromagnetic/electrothermal (EM/ET) gun development program during the subsequent two years and report progress in this technology to the Secretary of the Army. The Army was further directed to report the ASB findings to the Congress with the budget submissions for fiscal years 1991 and 1992.

The attached ASB report, "Electromagnetic/Electrothermal Gun Technology Development" is the second report provided in response to these Congressional directives. This year the special ASB panel which reviewed the Army's program found that EM/ET gun technology offers significant potential benefits to the Army but given recent test results is not ready for near term weaponization. In response to the report's conclusions, the Army's EM/ET program has been restructured to emphasize component maturation, the obtainment of a fundamental understanding of hypervelocity ballistics, and the exploration of innovative system concepts. Attached at the end of the report is a letter from Dr. Eaton, the ASB study chairman, supporting the Army's efforts to comply with the findings of the ASB study.

The additional funding provided by the 101st Congress for an enhanced Army EM/ET gun program is indicative of the enthusiasm shared by both government and industry for this exciting technology and its long term promise. The Army looks forward to your continued support.

Sincerely,

George T. Singley III
Deputy Assistant Secretary
For Research and Technology

Attachment

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

22 MAR 1991

The Honorable Les Aspin
Chairman
Committee on Armed Services
House of Representatives
2120 Rayburn House Office Building
Washington, D. C. 20515-6035

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